APPARATUS AND METHOD FOR RETRACTING AN ACTUATOR

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Field of the Invention

This application relates generally to data storage devices and more particularly to actuator retraction when power to a disc drive or other such data storage device is interrupted.

Background of the Invention

Disc drives are data storage devices that store digital data in optical/magnetic form on a rotating storage medium. Modern magnetic disc drives comprise one or more information storage discs that are coated with a magnetizable medium and mounted on the hub of a spindle motor for rotation at a constant high speed. Information is stored on the discs in a plurality of concentric circular tracks typically by an array of transducers ("heads") mounted to a radial actuator for movement of the heads in an arc across the surface of the discs. Each of the concentric tracks on each surface is generally divided into a plurality of separately addressable data sectors. The recording transducer, e.g. a head carrying a magnetoresistive read element and an inductive write element, is often referred to as a read/write head. The head is used to transfer data between a desired track and an external environment. During a write operation, data is written onto the disc track and during a read operation the head senses the data previously written on the disc track and transfers the information to a host computing system. The overall capacity of the disc drive to store information is dependent upon the disc drive recording density.

The transducers (heads) are mounted on gimbals and supported via flexures at the distal ends of a plurality of actuator arms that project radially outward from the actuator body. The actuator body pivots about a shaft mounted to the disc drive base plate at a position closely adjacent the outer edges of the discs. The pivot shaft is parallel with the axis of rotation of the spindle motor and the discs, so that the transducers move in planes parallel with the surfaces of the discs.

Such rotary actuators typically employ a voice coil motor to position the transducers with respect to the disc surfaces. The actuator voice coil motor includes a voice coil extending or projecting from the actuator body in a direction opposite the actuator arms and immersed in the magnetic field formed by one or two bipolar permanent magnets. When controlled direct current is passed through the coil, an electromagnetic field is set up which interacts with the magnetic field of the magnetic circuit to cause the coil to move in accordance with the well-known Lorentz relationship. As the coil moves, the actuator body pivots about the pivot shaft and the transducers move across the disc surfaces. The actuator thus allows the transducers to move back and forth in an arcuate fashion between an inner diameter and an outer diameter of the disc stack.

When the disc drive is de-energized, the transducers are automatically moved to a storage location or "park" location, either on the disc surfaces, or on a ramp off of the surfaces. The park location is typically adjacent and outside the inner or outer periphery of the data storage region of the disc surface and, if located on the disc, is typically called a landing zone. This landing zone typically does not contain any useable data as the transducer physically contacts the disc at rest. Consequently, any data stored in this area would likely be lost or compromised. In addition, the landing zone is typically roughened to minimize the stiction of the transducer against the disc surface.

Some disc drives utilize load/unload ramps to facilitate the removal of the transducer from the disc to a parked position adjacent the disc. The load/unload ramp in a disc drive is typically stationary and located at a peripheral portion of the information storage disc. Removal of the transducer from the disc is accomplished by the transducer/suspension assembly moving to the outer rim portion of the disc and then traversing up an inclined portion of the ramp to a park location on the load/unload ramp. As such, the transducers are physically "parked" off of the disc surfaces.

In this latter case, the transducers must be removed from the disc with precision to ensure proper disc drive operation. On one hand, the transducers will not be removed from the disc if the actuator is retracted and contacts the

load/unload ramp at a speed below the lower end of a nominal velocity required to traverse the ramp. On the other hand, the transducers may become damaged if the actuator reaches the ramp at a speed outside the nominal velocity window. Thus, the retraction velocity of the actuator must be precisely controlled within a nominal velocity range. Against this backdrop the present invention has been developed.

Summary of the Invention

A disc drive in accordance with an embodiment of the present invention includes one or more information storage discs mounted on a spindle motor for rotating the discs, and an actuator assembly mounted on a base plate adjacent the discs. The information storage disc surfaces are preferably partitioned into zones. The actuator assembly typically carries a transducer for each surface and positions one transducer over each one of the surfaces of the information storage disc. The actuator assembly, in accordance with embodiments of the present invention, retracts the transducer(s) from the information storage disc, or discs, in response to a retraction voltage applied for a retraction time interval such that the actuator assembly reaches the park position at a predetermined velocity. The retraction voltage and retraction time interval are calculated based on the location of the transducer over the surface of the information storage disc.

The values of the retraction voltage and the retraction time interval are continually updated in a retraction data table. The retraction data table organizes the data based on the zone associated with the location of the transducer before the actuator assembly retracts the transducer. During most periods of drive operation, the drive is operating in a track following mode. Default values for the retraction voltage and the retraction time interval are retrieved from the retraction data table when power to the disc drive is unexpectedly interrupted. The retrieved values are applied such that the actuator assembly reaches the park position at the predetermined velocity.

The disc drive may, however, be operating in seek mode when power to the disc drive is interrupted. A brake time interval is calculated based on the velocity of the actuator assembly when power to the disc drive is interrupted. A

brake is applied for the brake time interval to halt movement of the actuator assembly before the retraction voltage is applied as described above. Values of the brake time interval are continually updated in a brake data table. The brake data table organizes the data based on the zone associated with the location of the transducer when the brake is applied. A default value for the brake time interval is retrieved from the brake data table when power to the disc drive is unexpectedly interrupted. The brake is applied for the retrieved brake time interval before the retraction voltage is applied.

These and various other features as well as advantages which characterize the present invention will be apparent from a reading of the following detailed description and a review of the associated drawings.

Brief Description of the Drawings

FIG. 1 is a plan view of a disc drive incorporating a preferred embodiment of the present invention showing the primary internal components.

FIG. 2 is a flow diagram illustrating a process for preparing for actuator retraction when power to the disc drive is abnormally interrupted in accordance with a preferred embodiment of the present invention.

FIG. 3 is a flow diagram illustrating a process for retracting an actuator when power to the disc drive is abnormally interrupted in accordance with a preferred embodiment of the present invention.

Detailed Description

A disc drive **100** constructed in accordance with a preferred embodiment of the present invention is shown in FIG. **1**. The disc drive **100** includes a base **102** to which various components of the disc drive **100** are mounted. A top cover (not shown) cooperates with the base **102** to form an internal, sealed environment for the disc drive in a conventional manner. The components include a spindle motor **104**, which rotates one or more discs **106** at a constant high speed. Information is written to and read from tracks **105** on the discs **106** through the use of an actuator assembly **108**, which rotates during a seek operation about a bearing shaft assembly **110** positioned adjacent the discs **106**.

The actuator assembly **108** includes a plurality of actuator arms **112** which extend towards the discs **106**, with one or more flexures **114** extending from each of the actuator arms **112**. Mounted at the distal end of each of the flexures **114** is a transducer **116** which is carried by a fluid bearing slider (not shown) enabling the transducer **116** to fly in close proximity above the corresponding surface **117** of the associated disc **106**. Additionally, extending laterally from the distal end **118** of the flexure **114** is a lift tab **118** for engagement with a load/unload ramp **122**.

During a seek operation, the track **105** position of the transducer **116** is controlled through the use of a voice coil motor (VCM) **126**, which typically includes a coil **128** attached to the actuator assembly **108**, as well as one or more permanent magnets **130** which establish a magnetic field in which the coil **128** is immersed. The controlled application of current to the coil **128** causes magnetic interaction between the permanent magnets **130** and the coil **128** so that the coil **128** moves in accordance with the well-known Lorentz relationship. As the coil **128** moves, the actuator assembly **108** pivots about the bearing shaft assembly **110**, and the transducers **116** are caused to move across the surfaces of the discs **106**.

The spindle motor **104** is typically de-energized when the disc drive **100** is not in use for extended periods of time or when a system reset is triggered. The transducers **116** are moved over the surfaces **117** of the discs **106** to the load/unload ramp **122** located at the outer diameter **132** of the information storage discs **106**. The transducers **116** traverse onto the load/unload ramp **122** and are secured in position through the use of an actuator latch arrangement (not shown), which prevents inadvertent rotation of the actuator assembly **108** when the transducers **116** are parked.

The actuator assembly **108** retracts to park the transducers **116** on the load/unload ramp **122** in response to a constant retraction voltage applied to the VCM **126**. The actuator assembly **108** is retracted at a speed within a predetermined nominal retraction velocity range when the retraction voltage is applied to the VCM **126** for a retraction time interval, i.e., the length of time that the retraction voltage is applied to the VCM **126**. The values of the retraction

voltage and the retraction time interval vary depending on the location of the transducer **116** over the surface **117** of the disc **106**. Values for the retraction voltage and the retraction time interval are calculated each time the actuator assembly **108** is to be retracted under normal disc drive operating conditions. The retraction voltage and retraction time interval are calculated as follows.

When the disc drive is in track following mode immediately following the brake stage of a seek operation, the distance traveled is:

$$d_{point} = d_{initial} \pm d_{btravel} + d_0$$

where d_{point} is defined as the final head location;

$d_{initial}$ is defined as the actuator assembly position upon power loss;

$d_{btravel}$ is defined as the distance travelled while brake is applied; and

d_0 is defined as the distance between the load/unload ramp and the first data track.

When the disc drive is in track following mode the brake is not applied. Thus, $d_{btravel}$=0, then

$$d_{point} = d_{initial} + d_0$$

The target angular velocity (ω_{target}) is determined by the following relationship.

$$Accel_{cvr} = \frac{\omega_{target}^2}{2 * d_{point}} \qquad \text{eq(1)}$$

where

$$Accel_{cvr} = \frac{K_t}{J} * I_{vcm}, \qquad \text{eq(2)}$$

and

$$I_{vcm} = \frac{V_{cvr}}{R_{vcm}} \qquad \text{eq(3)}$$

where J is the moment of inertia of the actuator;

K_t is the torque constant of the actuator assembly; and

I_{vcm} is the available current that can be drawn from the system, which is a constant.

Combining eq(2) & eq(3), the retraction voltage (V_{cvr}) is:

$$V_{cvr} = \frac{K_t}{J * R_{vcm}} * Accel_{cvr} \qquad \text{eq(4)}$$

further substituting eq(1) into eq(4), the retraction voltage becomes:

$$V_{cvr} = \frac{K_t}{J} * \frac{\frac{\omega_{t\arg et}^2}{2 * d_{point}}}{R_{vcm}} = \frac{K_t}{2 * J * R_{vcm}} * \left[\frac{\omega_{t\arg et}^2}{d_{point}}\right] = \frac{K_t}{2 * J * R_{vcm}} * \left[\frac{\omega_{t\arg et}^2}{d_{point}}\right]$$

or simplified as:

$$V_{cvr} = K_{cvr} / d_{point}, \qquad \text{eq(5)}$$

where $K_{cvr} = \dfrac{K_t * \omega_{t\arg et}^2}{2 * J * R_{vcm}}$

The corresponding retraction time interval (t_{cvr}) applied for the retraction voltage scheme to achieve nominal speed at the load/unload ramp is,

$$t_{cvr} = \frac{\omega_{t\arg et}}{Accel_{cvr}} = \frac{\omega_{t\arg et}}{\frac{K_t}{J} * I_{vcm}} = \frac{\omega_{t\arg et} * R_{vcm}}{\frac{K_t}{J} * V_{cvr}},$$

$$t_{cvr} = \frac{K_{time}}{V_{cvr}}, \qquad \text{eq(6)}$$

where $K_{time} = \dfrac{\omega_{t\arg et} * R_{vcm}}{\frac{K_t}{J}}$

eq (5) and eq(6) are used to create the retraction data table.

The disc drive **100** may be in either seek or track following mode when the actuator assembly **108** is to be retracted upon an unexpected loss of power. The retraction voltage is applied immediately upon power loss to retract the actuator assembly **108** if the disc drive **100** is in track following mode. A brake (not shown) is first applied initially to halt movement of the actuator assembly **108** if a seek operation of the disc drive **100** is interrupted due to the power failure. Then, the retraction voltage is applied to retract the actuator assembly **108** after the brake is applied for a predetermined brake time interval.

The brake time interval, i.e., the length of time that the brake is applied to the actuator assembly **108**, varies depending on the location of the transducers **116** over the surfaces **117** of the disc **106** and the velocity of the actuator assembly **108**. The value for the brake time interval associated with different locations on the surface **117** of the disc **106** is calculated each time the brake is to be applied to the

actuator assembly **108** under normal disc drive operating conditions. The brake time interval (t_{brake}) is calculated as shown below.

$$\omega_{final} = \omega_{initial} + (Accel_{brake} * t_{brake})$$

where $Accel_{brake}$ is the brake capability;

$\omega_{initial}$ is the speed of the actuator upon power loss; and

ω_{final} is the speed of the actuator after the brake is applied.

ω_{final} is expected to be equal to zero.

Hence, the brake time interval is

$$t_{brake} = \frac{\omega_{initial}}{Accel_{brake}} \qquad \text{eq(7)}$$

The brake capability ($Accel_{brake}$) uses the maximum current that can be drawn from the system (I_{vcm}).

$$Accel_{brake} = \frac{K_t}{J} * I_{vcm} \qquad \text{eq(8)}$$

Since K_t, J and I_{vcm} are constants, $Accel_{brake}$ is fixed.

The brake time interval (t_{brake}) can be calculated as:

$$t_{brake} = \frac{J}{K_t * I_{vcm}} * \omega_{initial}$$

t_{brake} can be simplified as:

$$t_{brake} = K_{brake} * \omega_{initial}, \qquad \text{eq(9)}$$

where $K_{brake} = \dfrac{J}{K_t * I_{vcm}}$

From eq(9), the brake time interval (t_{brake}) is proportional to $\omega_{initial}$, where $\omega_{initial}$ is the actuator speed used to point to the brake data table to retrieve the brake time interval.

With the brake time interval (t_{brake}), the distance travelled during braking ($d_{btravel}$), can be calculated as:

$$d_{btravel} = \omega_{initial} * t_{brake} + \frac{1}{2} * Accel_{brake} * t_{brake}^2 \qquad \text{eq(10)}$$

substitute eq(7) & eq(8) into eq(10)

$$d_{btravel} = 1.5 * \frac{\omega_{initial}^2}{Accel_{brake}}$$

$$d_{btravel} = \left(\frac{1.5J}{K_t * I_{vcm}}\right) * \omega_{initial}^2 \qquad \text{eq(11)}$$

$$d_{btravel} = K_{const} * \omega_{initial}^2,$$

$$\text{where } K_{const} = \frac{1.5J}{K_t * I_{vcm}}$$

So the final head location (d_{point}) is given:

$$d_{point} = d_{initial} \pm d_{btravel} + d_0 \qquad \text{eq(12)}$$

It is important to note that d_{point} will act as a pointer to point to the retraction data table to retrieve a suitable retraction voltage and retraction time interval.

In one embodiment of the invention, the surface **117** of the disc **106** is partitioned into eight concentric zones. The retraction data table includes values for retraction voltage and retraction time interval corresponding to each zone. The retraction data table is updated each time a new value is calculated for the retraction voltage and the retraction time interval. Likewise, the brake data table includes values for the brake time interval corresponding to each zone. The brake data table is also updated each time a new value is calculated for the brake time interval. The data tables are continually updated during normal operation of the disc drive **100**. The data tables are updated by a serial port command from a microprocessor to a control circuit of the spindle motor **104** and the VCM **126**.

The retraction voltage, retraction time interval and brake time interval are calculated from values of the transducer **116** location and the actuator assembly **108** velocity. Neither of these parameters is available when power to the disc drive **100** is unexpectedly interrupted outside normal disc drive operation. For example, power to the disc drive may be suddenly interrupted due to the removal of a plug of a computer from an electrical power outlet or local power outage caused by an electrical storm. Updating the data tables ensures that default values for retraction voltage, retraction time interval and brake time interval are available to retract the actuator assembly **108** when power to the disc drive **100** is unexpectedly interrupted. The appropriate values for retraction voltage, retraction time interval and brake time interval corresponding to the zone location of the transducers **116**

when power to the disc drive **100** is unexpectedly interrupted can be retrieved from the data tables to retract the actuator assembly **108** at a velocity within a predetermined nominal range.

A process for preparing for actuator assembly retraction when power to the disc drive 100 is abnormally interrupted in accordance with one preferred embodiment of the present invention is shown in FIG. **2**. The process begins in Operation **200**. Process control then transfers to Operation **210**. Operation **210** is bypassed if the information storage disc **106** is partitioned into a number of zones. If the disc **106** is not yet partitioned, the information storage disc **106** is partitioned into a number of zones. Process control then transfers to Query Operation **220**. In Query Operation **220** the current operational mode of the actuator assembly **108** is determined, i.e., whether the actuator assembly **108** is in a seek mode or a track following mode. Process control transfers to Operation **260** if the actuator assembly **108** is in track following mode. Process control transfers to Operation **230** if the actuator assembly **108** is in seek mode.

If the actuator assembly **108** is in seek mode, in Operation **230** the brake time interval is calculated based on the actuator assembly velocity. Process control then transfers to Operation **240**. In Operation **240** the brake data table is updated with the calculated value for the brake time interval. Process control then transfers to Operation **260**.

In Operation **260** the retraction voltage and a retraction time interval are calculated based on the zone location of the transducer **116** over the surface **117** of the information storage disc **106**. Process control then transfers to Operation **270**. In Operation **270** the retraction data table is updated with the calculated values for the retraction voltage and retraction time interval. Process control ends in Operation **290**.

An exemplary process in accordance with the present invention for retracting an actuator assembly **108** when power in the disc drive **100** is unexpectedly interrupted is shown in FIG. **3**. The process begins in Operation **300**. Here, registers are initialized. Process control then transfers to Query Operation **310**. In Query Operation **310** the operational mode of the actuator

assembly **108** is ascertained, i.e., track following mode or seek mode. Process control transfers to Operation **340** if the actuator assembly **108** is in track following mode. Process control transfers to Operation **320** if the actuator assembly **108** is in seek mode.

In Operation **320**, if the actuator assembly **108** is in seek mode the updated value for the brake time interval is retrieved from the brake data table based on the zone location of the transducer **116**. Process control then transfers to Operation **330**. In Operation **330** the brake is applied for the updated brake time interval to halt movement of the actuator assembly **108**. Process control then transfers to Operation **340**.

In Operation **340** the updated values for the retraction voltage and retraction time interval are retrieved from the retraction data table based on the zone location of the transducer **116**. Process control then transfers to Operation **350**. In Operation **350** the updated value of the retraction voltage is applied for the updated retraction time interval such that the actuator assembly **108** contacts the load/unload ramp **122** at a velocity within a predetermined nominal range. Process control ends in Operation **360**.

It will be clear that the present invention is well adapted to attain the ends and advantages mentioned as well as those inherent therein. While a presently preferred embodiment has been described for purposes of this disclosure, various changes and modifications may be made which are well within the scope of the present invention. For example, the nominal range of values may be other than as described above. Numerous other changes may be made which will readily suggest themselves to those skilled in the art and which are encompassed in the spirit of the invention disclosed and as defined in the appended claims.